A three-frequency audiogram for use in industry

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ABSTRACT Some form of audiometric screening forms part of any comprehensive hearing conservation programme, but because of the large numbers of workers exposed to noise, it is suggested that routine audiometry using an 8-frequency test preceded by history and examination makes undue demands on limited resources. It is proposed that a simple 3-frequency test without prior preparation of subjects is adequate for the purposes of industrial audiometry. Men whose hearing threshold was worse than 20 dB at 1, 2, or 4 kHz were considered to have failed the 3-frequency test and 150 such cases were randomly selected and subjected to a full 8-frequency audiogram. The results were then assessed for numerical accuracy and diagnostic reliability. The results of the 3-frequency test were marginally worse than the 8-frequency audiogram by 2.33 to 4.98 dB, and the comparison of the two tests as a diagnostic tool gave a concordance rate of 79%–80% ($p = 0.00001$) between the two physicians who examined the results and a level of interpersonal agreement of 87% for the 3-frequency test and 89% for the full audiogram. If audiometric screening is to be offered to the whole population at risk it should be simple, rapid, and accurate enough to detect hearing loss before disability develops so that those individuals may be counselled. It is suggested that the 3-frequency test fulfils this purpose, demonstrates the “reasonably practicable” approach of recent legislation, and does not unnecessarily divert resources from other key tasks in the practice of occupational medicine.

A large number of workers are exposed to noise levels at work sufficient to cause some degree of noise induced hearing loss. It is estimated that 0.5m workers are exposed to noise levels of 90 dB(A) or more in the UK,¹ and the estimate by the Commission of European Communities, based on an exposure level of 85 dB(A), is between 10 and 15m within its member states.² After considerable debate in the early 1970s,^{3,4} it is now generally accepted that some form of audiometry is integral to any comprehensive hearing conservation programme. Where there are references to audiometry in industry, the recommendations are all based on 8-frequency pure tone testing of each ear preceded by a noise free interval, an occupational and medical history, and an otoscopic examination.⁵

The benefits of audiometry in the prevention of noise induced hearing loss are not as clear cut as the reduction of noise at source or the use of personal protection. Nevertheless, at least two discernible advantages can be recognised. Firstly, noise induced

hearing loss can be diagnosed from the audiometric trace, often before the individual has sustained any perceptible deficit. At this stage the individual can be counselled regarding the prevention of further auditory damage. Secondly, the results of periodic audiometry can be used to monitor the effectiveness of a hearing conservation programme, both for the individual and the group.

The increased demand for the inclusion of audiometry (in accordance with the recommended test procedure⁵) with other hearing protection measures¹ has resulted in a rigid, complex methodology. We do not believe that this level of sophistication is necessary for audiometric screening in industry to achieve its two objectives. Because of the resources required to perform audiometry in its suggested form, the availability of the test may of necessity be limited to certain groups within the total population at risk.

In 1970 the Royal Air Force introduced a large scale audiometric screening programme using a 3-frequency test procedure. The results were summarised by King in 1978.⁶ Men whose hearing loss exceeded 20 dB at 1 kHz, 20 dB at 2 kHz, and

Received 28 March 1983.
Accepted 11 July 1983

30 dB at 4 kHz were referred for further assessment. The fact that referrals fell from almost 9% in 1970 to just over 2% in 1976 and that there was "an annual yield of aurally disabled in the region of 2 per 1000 screened" indicates that this type of monitoring may be more appropriate to industry than the currently recommended procedure.

This paper presents a simple 3-frequency test based on the one used by the Royal Air Force and critically examines its accuracy and diagnostic value in comparison with an 8-frequency test. For the purposes of this comparison it is assumed that the 8-frequency test provides the best possible information on hearing status available to an occupational health service.

Materials and methods

The 3-frequency test is performed by the Hughson-Westlake method⁷ using a manual audiometer in an acoustic environment that meets the requirements laid down in the Health and Safety Executive's discussion document *Audiometry in Industry*.⁵ To minimise time away from the job, the test is administered as close as possible to the workplace. The hearing threshold of the worker is measured at 1, 2, and 4 kHz in the left and then the right ear. There is no prior preparation in terms of a noise free period, the taking of a history, or an otoscopic examination. Any individual whose hearing threshold is equal to, or better than, 20 dB at all three frequencies in each ear returns to work. Those with a threshold worse than 20 dB at one or more frequencies have an otoscopic examination by the nurse performing the audiometry. If wax occludes the auditory canal, arrangements are made for its removal and for retesting of the hearing threshold. Those who have a persistent loss of more than 20 dB at any frequency are referred for counselling.

To evaluate the accuracy of the 3-frequency test a random sample of 150 men who failed the referral criteria on the initial test subsequently underwent an 8-frequency audiogram in an acoustic booth using a Bekesy automatic audiometer. The results of the 3-frequency test were then compared with those of the 8-frequency audiogram to determine the level of numerical accuracy of the 3-frequency test.

To evaluate the 3-frequency test as a diagnostic investigation, a diagnosis was assigned for each ear on the results obtained both for this test and the 8-frequency test without reference to history or examination. We interpreted the results by using a double blind crossover approach and ascertained the level of intrapersonal agreement in interpretation of the 3 and 8-frequency tests. In addition, we established the level of interpersonal agreement in

Fig 1 Difference between 3-frequency and 8-frequency audiograms at 1 kHz.

interpretation of both tests.

Results

The difference between the 3-frequency and 8-frequency audiograms is normally distributed at each of the frequencies examined (figs 1-3). Also, at each frequency, the 3-frequency tests are on average worse by between 2.33 to 4.98 dB. This therefore represents a hearing threshold marginally worse than the level represented by the 8-frequency audiogram (table 1).

The standard deviation of the difference at 1 kHz is noticeably greater than at 2 or 4 kHz reflecting a wider spread of results. Further analysis of the 1 kHz results, dividing values for the left and right ear (figs 4 and 5), shows the results for the right ear to be similar to the overall results for 2 and 4 kHz (table 2). We believe that the wider variation in results for 1 kHz in the left ear is related to a learning effect since this is the first frequency tested. This should be eliminated by taking readings at 1, 2, and

Fig 2 Difference between 3-frequency and 8-frequency audiograms at 2 kHz.

Table 1 Accuracy of 3-frequency audiogram compared with 8-frequency audiogram

	Frequency 1 kHz	2 kHz	4 kHz
No of readings	300	300	300
Mean difference dB (3-frequency minus 8-frequency)	+4.98	+4.93	+2.33
Standard deviation dB (3-frequency minus 8-frequency)	8.30	7.44	7.69
Probable percentage of 3-frequency results that will actually exceed 30 dB at the referral level of 20 dB (from normal distribution probability tables)	3.59%	2.22%	5.48%

Table 2 Analysis of difference between 3-frequency and 8-frequency tests at 1 kHz

	Both ears	Left ear	Right ear
No of readings	300	150	150
Mean difference dB (3-frequency minus 8-frequency)	+4.98	+6.33	+3.68
Standard deviation dB (3-frequency minus 8-frequency)	8.30	8.37	7.48

Fig 3 Difference between 3-frequency and 8-frequency audiograms at 4 kHz.

Fig 4 Difference between 3-frequency and 8-frequency audiograms for left ear at 1 kHz.

Table 3

Evaluation of diagnostic potential of 3-frequency audiogram		
Physician A Physician B		
Percentage agreement between diagnosis from 3-frequency test versus 8-frequency test		
Concurrence of physicians on interpretation of audiograms		
Percentage agreement between both physicians on diagnosis from audiograms alone		
	79%	80%
	3-frequency	8-frequency
	87%	89%

4 kHz (in the left ear) followed by a repeat at 1 kHz. The second value at 1 kHz should be recorded as the true value.

The comparison of the 3-frequency test with the 8-frequency audiogram as a diagnostic tool in determining the cause of deafness gave a concordance rate of 79% and 80% ($p = 0.00001$) for the two physicians who examined the results. The level of interpersonal agreement on the diagnosis was 87% for the 3-frequency test and 89% for the 8-frequency test (table 3).

Fig 5 Difference between 3-frequency and 8-frequency audiograms for right ear at 1 kHz.

Discussion

In common with many investigations the use of the audiogram in the diagnosis of hearing loss involves a process of pattern recognition. The nature of this process is such that the larger the number of "points" making up the shape of the pattern, the greater will be the resolution of its shape and hence the accuracy in diagnosis. Equally, in the formation of a pattern a minimum number of "points" will be necessary, below which the shape of the pattern will be inadequate to formulate a diagnosis. We suggest that the minimum number of points for industrial audiometry is three, and this is supported by the diagnostic accuracy of the 3-frequency test. We consider that this level of diagnostic accuracy is adequate for the purposes of an audiometric screening procedure in industry.

Selection of 1, 2, and 4 kHz as the three frequencies for testing is based on the requirement of industrial audiometry to detect hearing loss and divide it into three broad entities: noise-induced hearing loss, conductive loss, and, of lesser importance, the higher frequency loss due to presbycusis. These frequencies provide the best pattern from which to differentiate conductive deafness and noise induced hearing loss as shown by the data contained in table 3. In addition, this choice of frequencies also provides limited information about the effect on speech frequencies.

The 4 kHz "notch" while not pathognomonic of noise induced damage is generally accepted as indicative of early loss although there may be individual deviations with dips at 3 or 6 kHz.⁸ In our series the mean hearing loss in those individuals considered to have noise induced loss was almost identical for 4 and 6 kHz (table 4). We would contend that 6 kHz is more likely to be affected by presbycusis, and thus the use of the 4 kHz frequency gives a more accurate assessment of noise induced loss.

Measurement of the loss at 3 kHz has been omitted from the test since the primary aim is to establish a pattern from which to obtain diagnostic information rather than the secondary purpose of obtaining information about speech frequencies. From table 4, however, it can be seen that the mean loss at 3 kHz

does in fact lie between that at 2 kHz and 4 kHz.

BS 5330 defines the threshold of social handicap as an average loss of 30 dB over 1, 2, and 3 kHz.⁹ Although a direct comparison with the 3-frequency test cannot be made, it is of interest to note the basis on which 20 dB loss at 1, 2, and 4 kHz was selected as the level below which the individual is referred for further assessment. At this level the probable percentage of individuals whose true hearing threshold is greater than 30 dB is 3.59%, 2.22%, and 5.48% at 1, 2, and 4 kHz respectively (table 1).

An audiometric screening programme is no different from any other large scale screening programme in industry which should be offered to the whole population at risk. It should aim to separate the normal from the abnormal and the latter should then proceed to further assessment. The objective must include the detection of hearing loss before disability develops in order to counsel affected individuals. We have shown that in terms of numerical accuracy the 3-frequency test compares favourably with the 8-frequency audiogram. Indeed, reassessment of hearing loss for the purposes of prescription under the Industrial Injuries Scheme^{10,11} has highlighted several major anomalies and casts doubt on the accuracy of 8-frequency audiometry under supposedly ideal conditions.¹² Absolute accuracy is therefore difficult to achieve and is in fact not necessary to attain the objectives of an industrial screening programme. We suggest that the level of accuracy of the 3-frequency test is adequate for this purpose.

In this paper we have considered the audiogram as an isolated test. In practice, however, in order to formulate a diagnosis an investigation is considered in the context of a history and examination. This is applied to the 3-frequency test after the initial screen, when the individuals who fail on the referral criteria attend for assessment and counselling. The advantage of this is that time is saved where individuals with normal hearing would otherwise be subjected to history taking and examination. When used in conjunction with a history and examination the 3-frequency test will undoubtedly achieve a higher quality than we have obtained in isolation, and it will provide adequate information to the industrial audiologist.

In conclusion, while we would not pretend that the 3-frequency audiogram is as numerically or diagnostically accurate as more complex and time consuming methods, it does provide an adequate realistic alternative. It demonstrates the "reasonably practicable" approach that is a keynote of recent health and safety legislations and does not unnecessarily divert medical resources from other key tasks in the practice of occupational medicine.

Table 4 Mean hearing loss at each frequency for 108 individuals who were considered to have noise-induced hearing loss

Frequency	Mean loss
2 kHz	15.72 dB
3 kHz	31.09 dB
4 kHz	41.32 dB
6 kHz	42.73 dB

Appendix

The 3-frequency test has been applied to an industrial population of 3500 men exposed to noise levels ranging from 75 dB(A) Leq to 98 dB(A) Leq. Of this group, about 50% passed the 3-frequency test and the remainder proceeded to individual counselling.

From this extensive practical experience of the 3-frequency test and by performing the 8-frequency test in accordance with the procedure recommended in *Audiometry in Industry*,⁵ an estimate of medical man-hours required for each technique may be made. The following example is based on a test population of 100 men and the man-hours refer to medical/nursing time only. No account is taken of the subjects' time away from work and consequent loss of production time.

Full audiometry*	Man-hours
Completion of questionnaire and otoscopic examination (15 minutes/subject)	25
Removal of impacted wax in 6% of cases	2
Performance of audiogram (15 minutes/subject)	25
Categorisation of results (6 minutes/audiogram)	10
Counselling of categories three and four cases (15 minutes/subject: 50 subjects)	12½
Total:	74½

*In accordance with appendix 4 *Audiometry in Industry*.

Three-frequency test	Man-hours
Performance of test (6 minutes/subject)	10
Counselling (15 minutes/subject: 50 subjects)	12½
Including removal of wax in 6% of cases	1
Full audiometry in 20% of cases	2½
Total	26

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